

Maya: Next Generation Modeling & Simulation Tools for Global Networks



UCLA: R. Bagrodia, M. Gerla, S. Lu, F. Paganini, M. Sanadidi, M. Takai

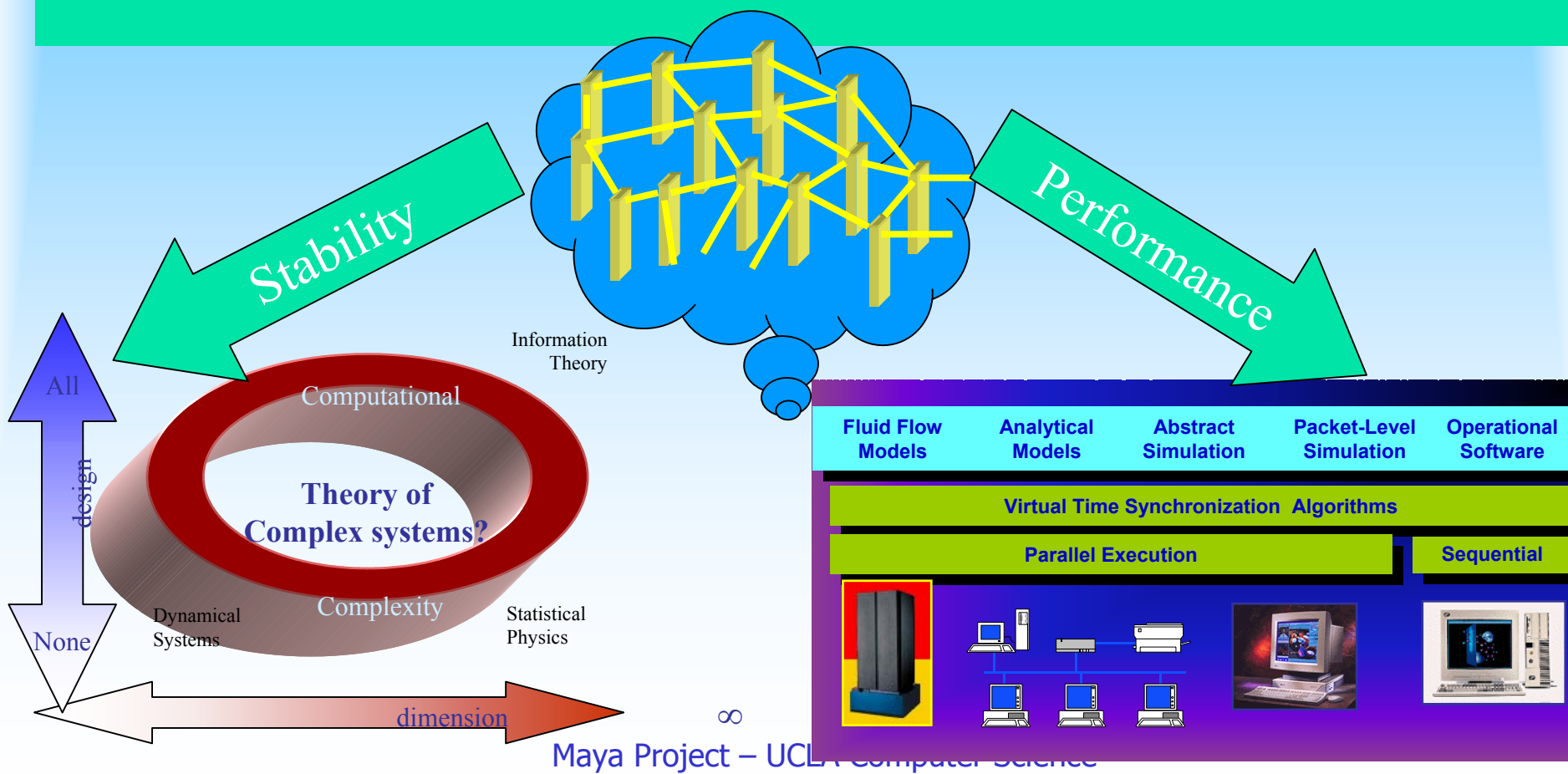
Caltech: M. Chandy, J. Doyle

DARPA PI Meeting, April, 2001

San Diego

Impact

- A *multi-resolution, multi-paradigm* integrated framework for network performance analysis: **Maya**
- A novel theory of network control and stability: **HOT**
- Adaptive network control using real-time simulations



Recent Results



- Network Stability: Paganini, Doyle
- Multi-paradigm models: Takai, Bagrodia
 - Mixed packet level simulation & Fluid flow models
 - Mixed operational software and packet level simulations
- TCP Westwood Analysis: Sanadidi, Gerla, et al
- Improving TCP performance in ad hoc networks: Lu

Integration of Fluid Flow Model into Packet Level Simulation



Maya Project – UCLA Computer Science

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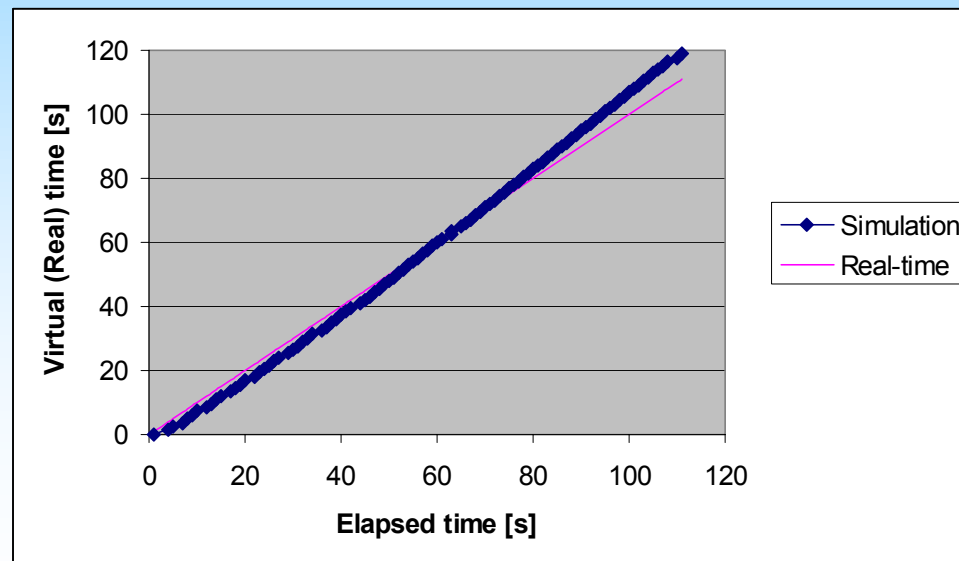
GloMoSim: Scalable Simulation Environment

- Layered Stack Design, simple APIs
- Detailed packet level simulation of wireless networks
- Comparative performance evaluation of alternative protocols

Application	TCP Applications (TELNET, FTP, HTTP), CBR
Transport	FreeBSD TCP and UDP
Network	Bellman-Ford, OSPF, WRP, Fisheye, AODV, DSR, LAR(scheme 1) and ODMRP
Data Link	CSMA, MACA, 802.11 DCF
Physical	BER and boundary models for packet receptions
Propagation	Free space, two-ray ground reflection, Trace based, SIRCIM

GloMoSim Sequential Runtime Performance

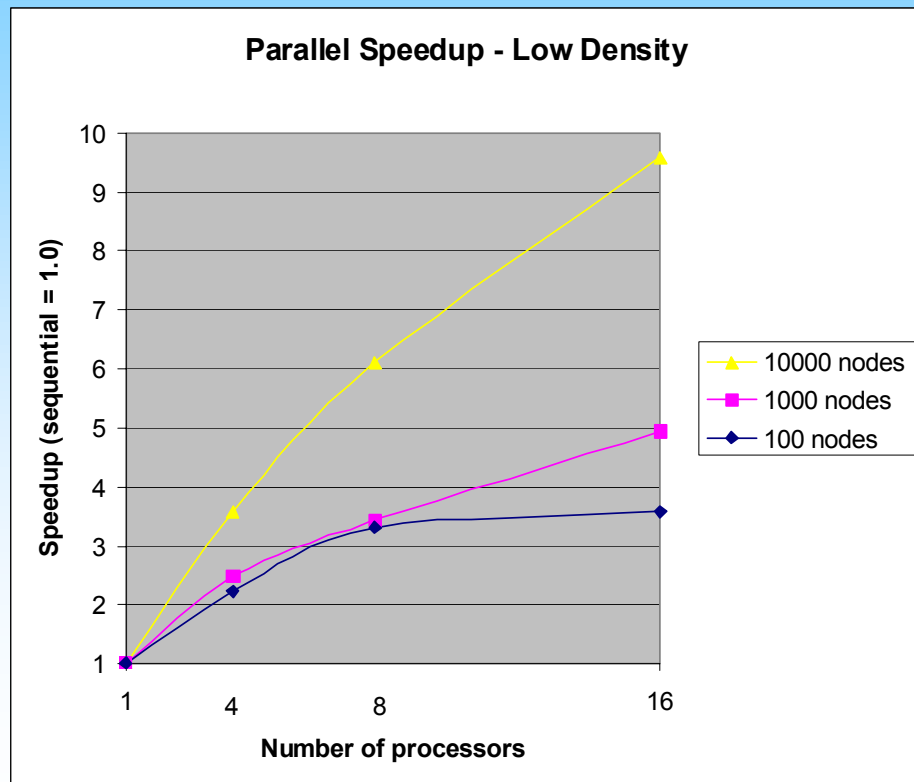
- Real-time simulation on a PC (Xeon 550MHz)
 - A 100 node network with 20,000 m² per node
 - 512 bytes, 4 pps CBR traffic given to 15% of nodes
 - 19020k events total, 169k events per second



Parallel Runtime Performance

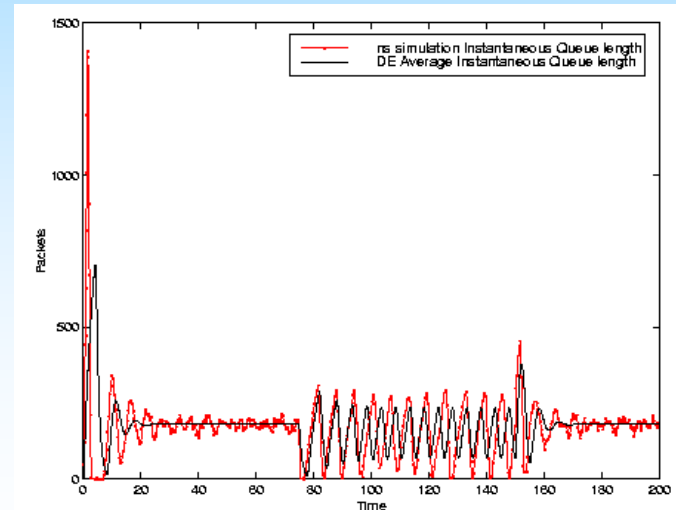
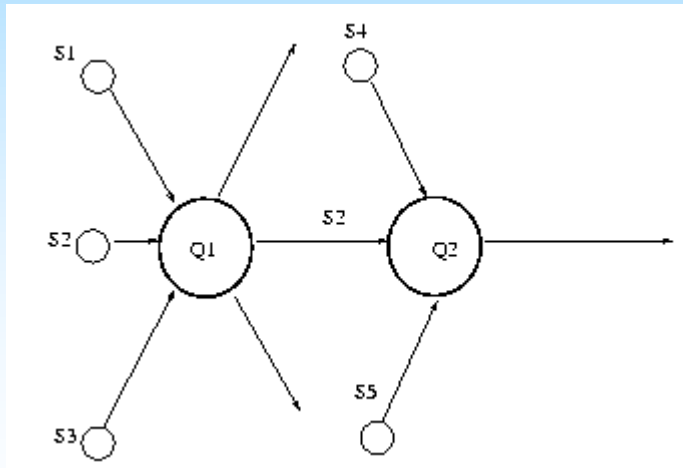
■ Parallel simulation on Sun Enterprise 6500

- 512 bytes, 20pps CBR traffic given to 15% of nodes
- 50,000m² per node (8.8 neighbors)
- LAR scheme 1 (On-demand ad hoc routing protocol)
- IEEE 802.11 DCF MAC + DSSS PHY radio



Fluid-Flow Model(TCP Flow Modeling with AQM)

- Proposed by Vishal Misra, Wei-Bo Gong, Don Towsley (U Massachusetts)
- TCP flows and AQM routers modeled by Stochastic Differential Equations (SDEs)
- Transform SDEs into Ordinary Differential Equations to be solved numerically
- Application to RED: obtain expected transient behavior of queue lengths, round trip time and TCP flow throughputs





Fluid-Flow based TCP Model

■ Notations:

- $W_i(t)$, $R_i(t)$ – Window size and round trip time of i th TCP connection
- $q(t)/C$ – Queueing delay at congested router
- $p(x)$ – loss function for AQM policy
- τ - one round trip delay

■ Window size of i th TCP Connection:
$$\frac{d\bar{W}_i}{dt} = \frac{1}{R_i(\bar{q})} - \frac{\bar{W}_i \bar{W}_i(t - \tau)}{2R_i(\bar{q}(t - \tau))} p(x(t - \tau))$$

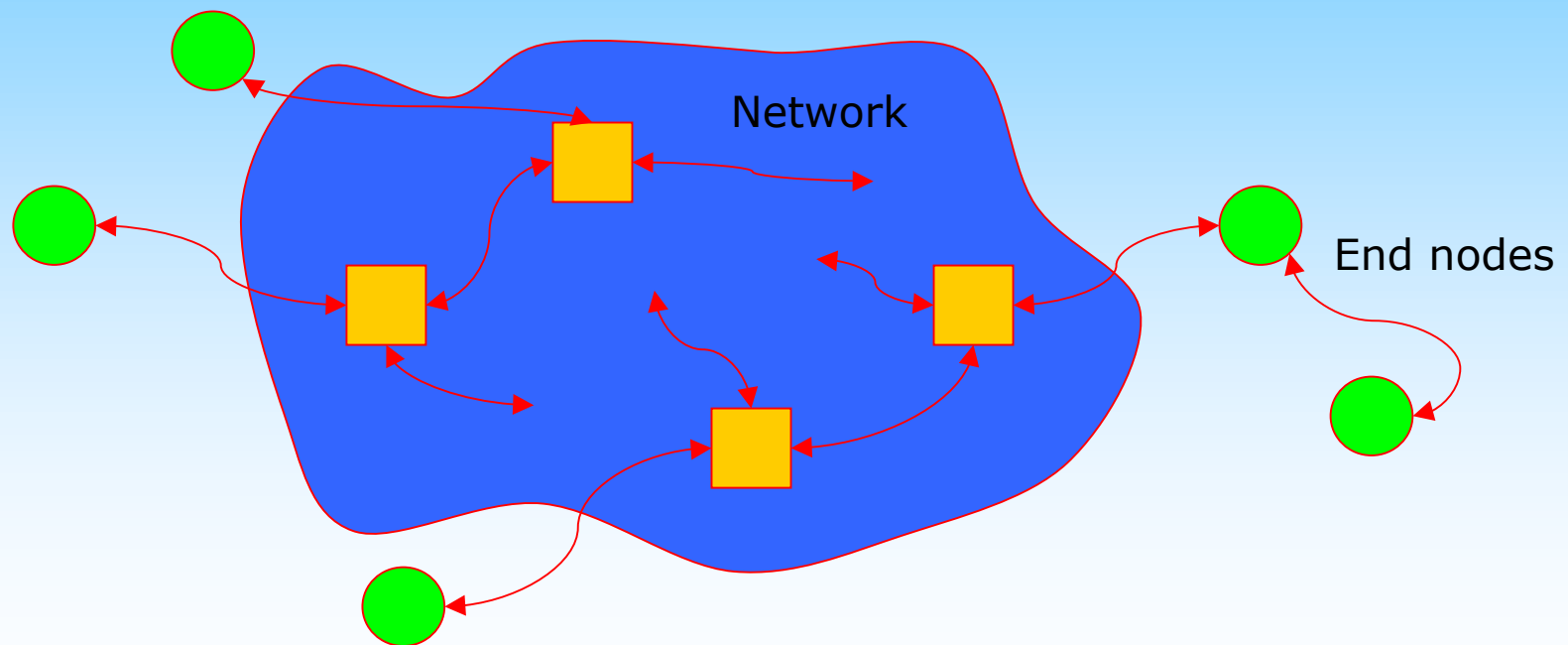
■ Queue Length estimate:
$$\frac{d\bar{q}}{dt} = -C + \sum_{i=1}^N \frac{\bar{W}_i}{R_i(\bar{q})}$$

■ Average Queue Length is an exponential average:
$$\frac{dx}{dt} = \frac{\ln(1 - \alpha)}{\delta} \bar{x}(t) - \frac{\ln(1 - \alpha)}{\delta} \bar{q}(t)$$

- Can be extended to network of routers

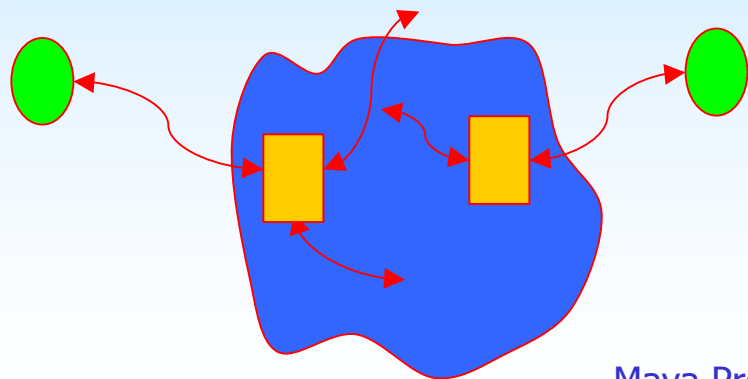
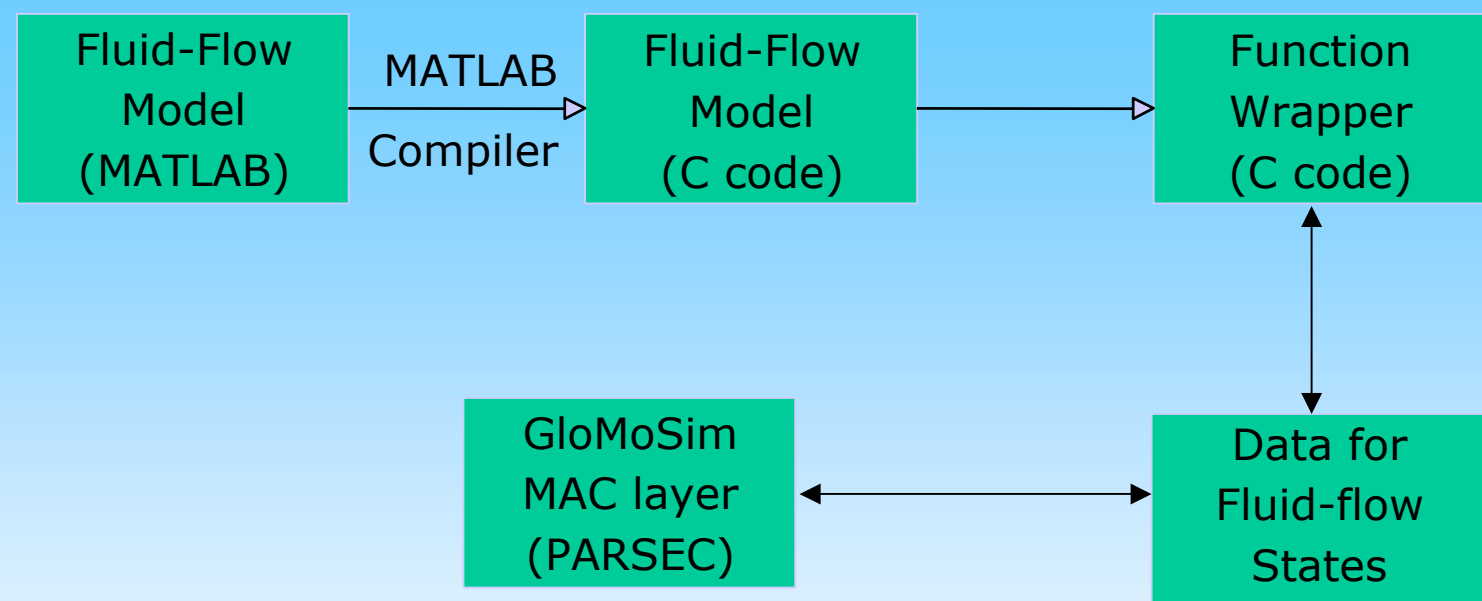
Integration of Fluid Flow into Packet Level Simulation (1)

- Increased applicability of fluid flow models: use packet level simulation for subnets where fluid flow model is inapplicable (e.g. wireless LAN) or inaccurate
- Better scalability compared to pure packet level simulation



Integration of Fluid Flow into Packet Level Simulation (2)

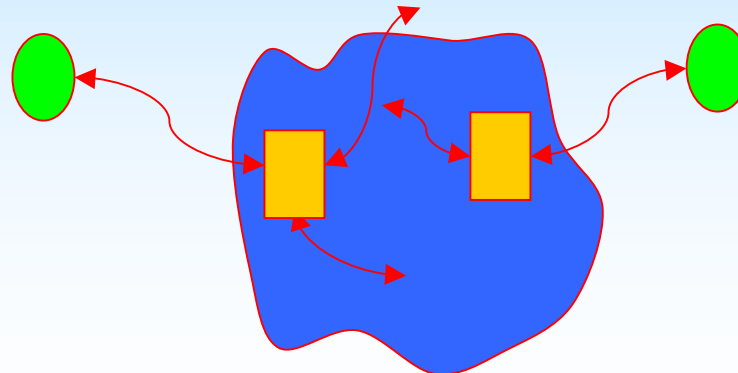
- Current code structure with data flow



Integration of Fluid Flow & Packet Level Models

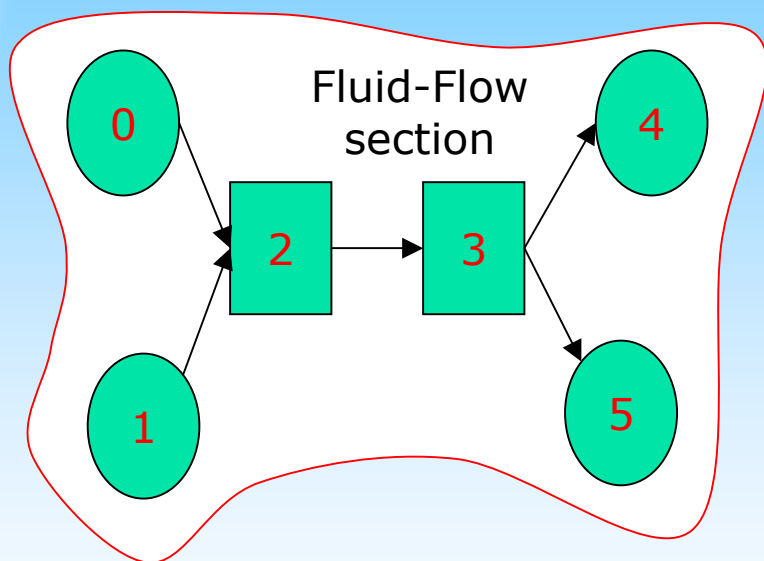
Interface from **GloMoSim** to **fluid-flow**: Complete

- allows UDP traffic flowing into fluid-flow model
- Support for light traffic cases: Complete
 - averages instantaneous data rate changes to reduce the number of fluid-flow model calls
- Interface from **fluid-flow** to **GloMoSim**: In progress
 - allows TCP connections between GloMoSim nodes via fluid-flow
 - delivers packets to GloMoSim nodes after estimated delays given by the fluid-flow model

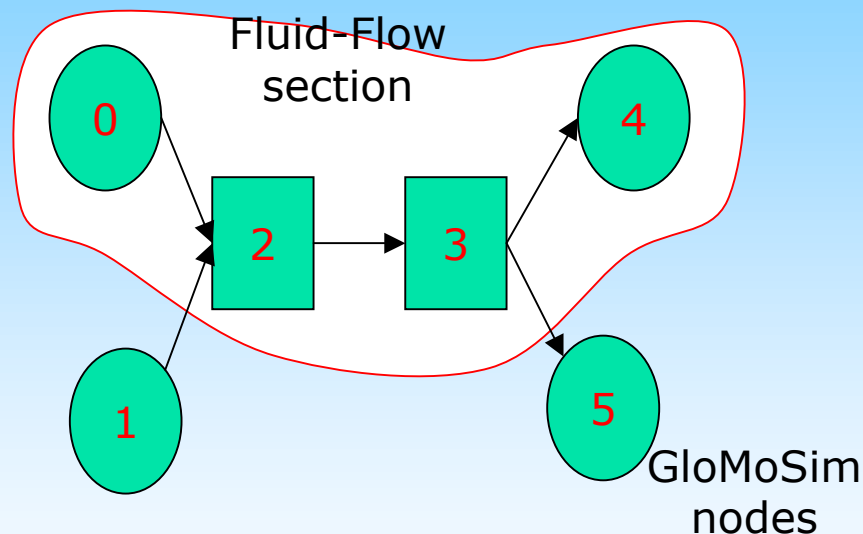


Network Topology for the Experiments

- TCP Connection (FTP): Node 0 → Node 2 → Node 3 → Node 4
- UDP Connection (CBR): Node 1 → Node 2 → Node 3 → Node 5



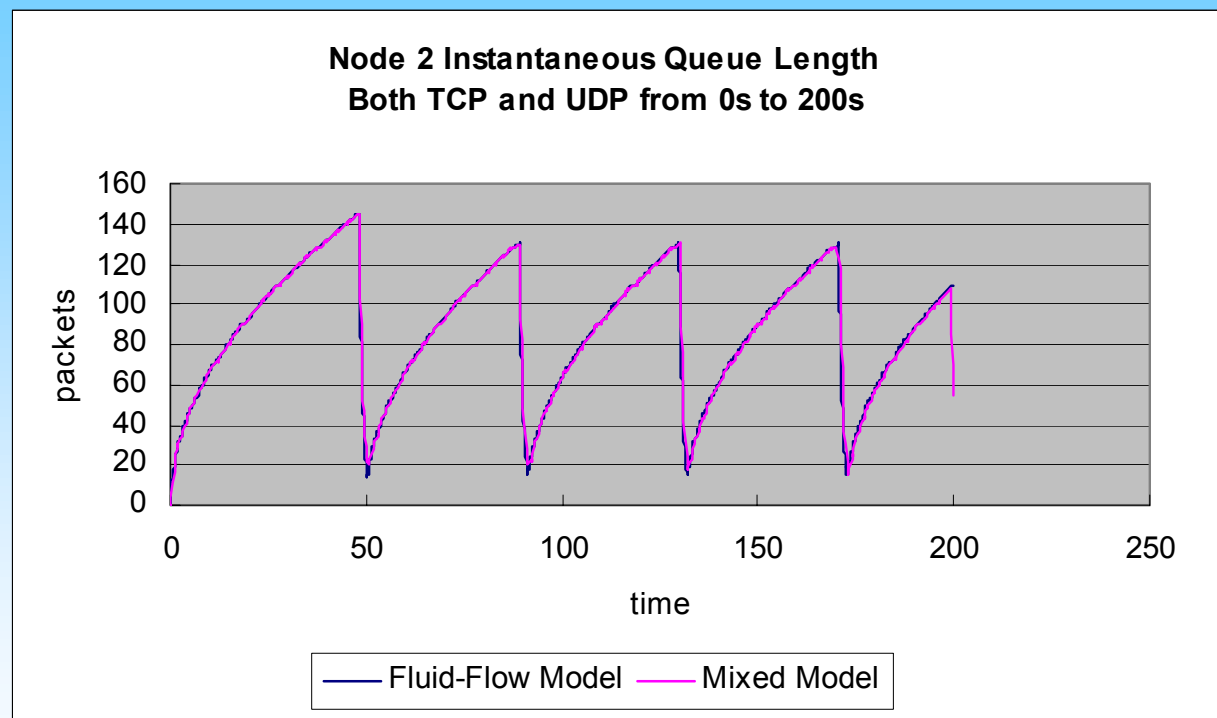
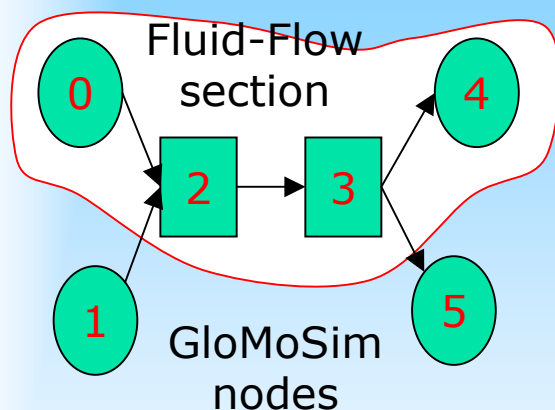
**Fluid-Flow
Analytical Model
Simulation**



**GloMoSim +
Fluid-Flow
Simulation**

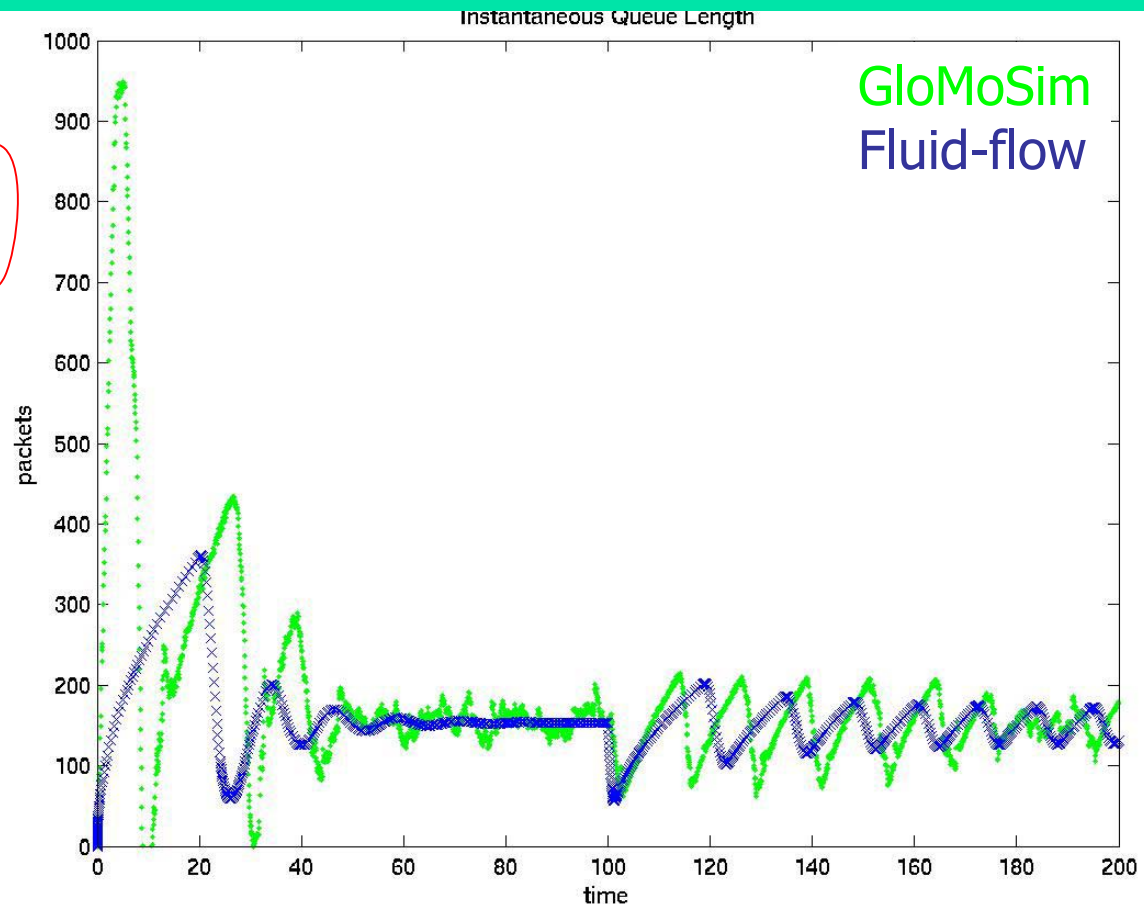
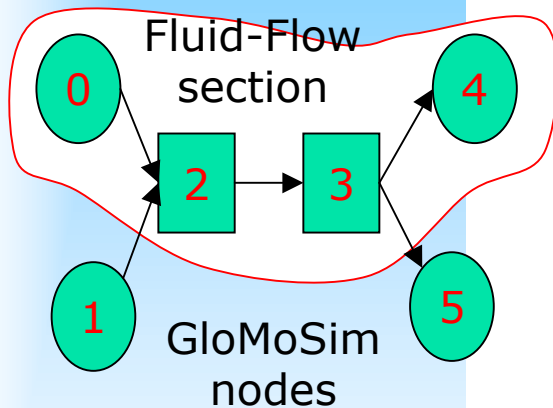
Mixed Mode Simulations (1)

- One TCP from Node 0 to 4, One UDP (1Mbps) from Node 1 to 5
- Both TCP and UDP flows start at 0s through 200s



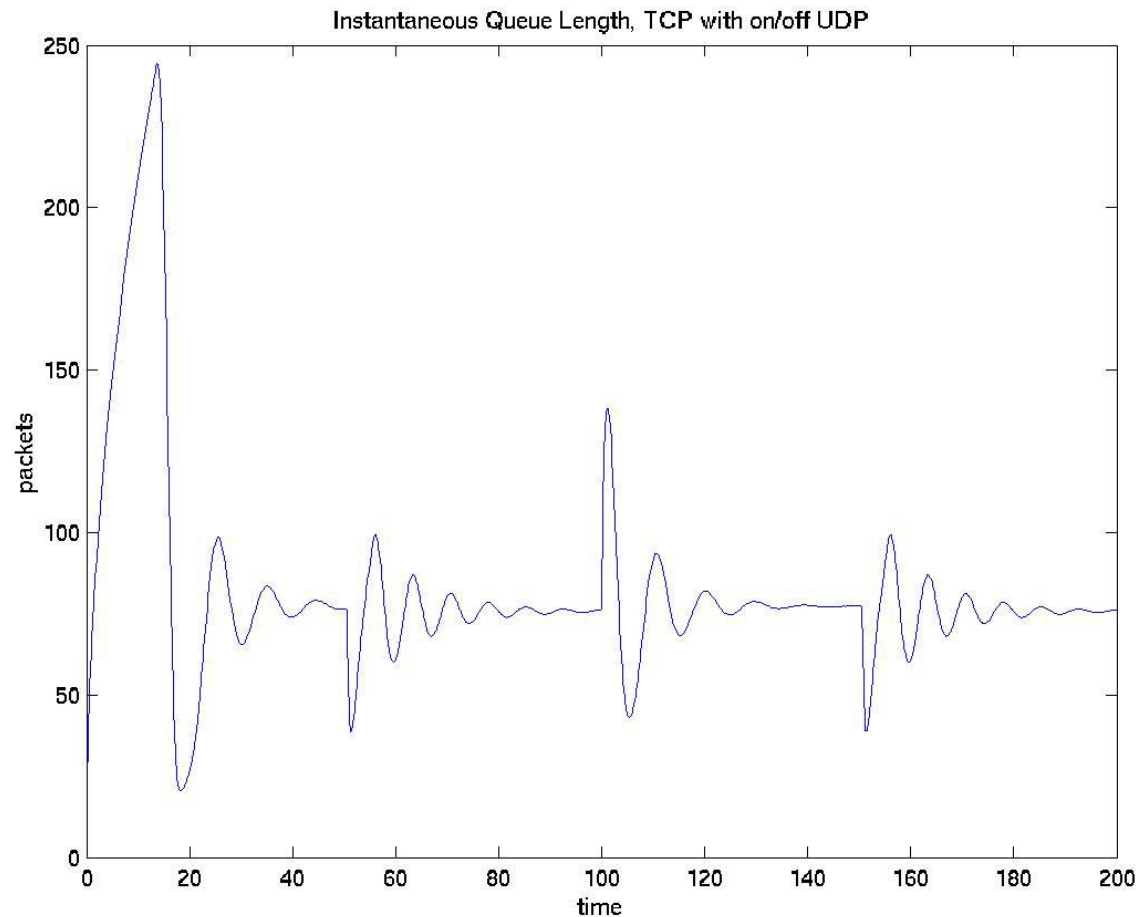
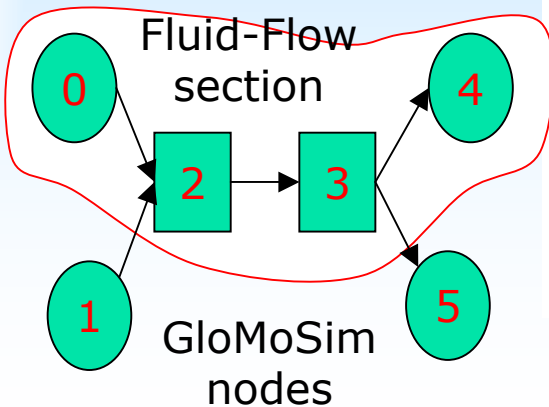
Validation of Fluid Flow Model against GloMoSim

- Node 0 to 4 and Node 1 to 5: 15 TCP flows until 100s, and 5 thereafter
- Instantaneous queue lengths change more gradually in GloMoSim, but both follow the same trend



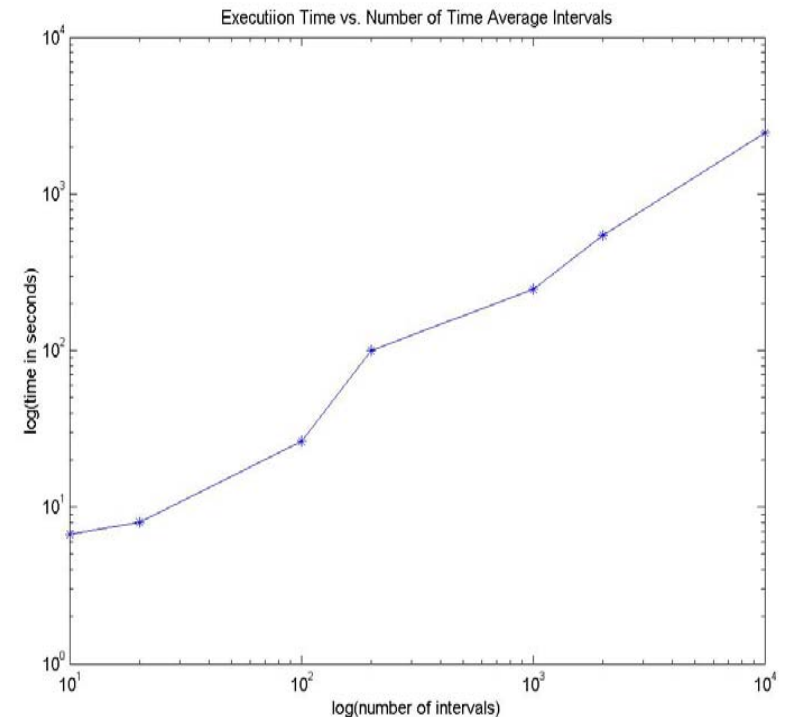
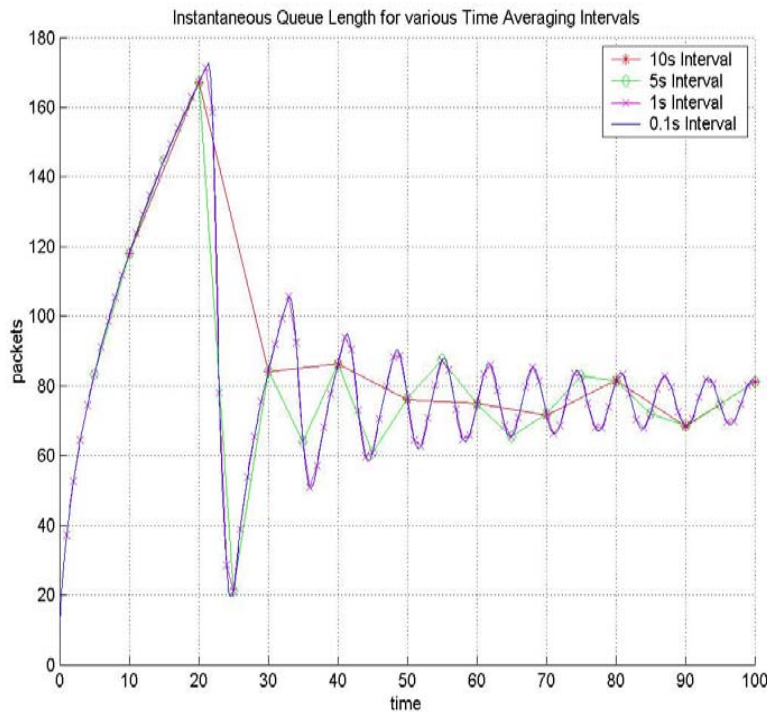
Mixed Mode Simulations (2)

- Ten TCP from Node 0 to 4, One UDP (1Mbps) from Node 1 to 5
- All TCP connections start at around 0s
- UDP traffic is on from 0s to 50s and 100s to 150s



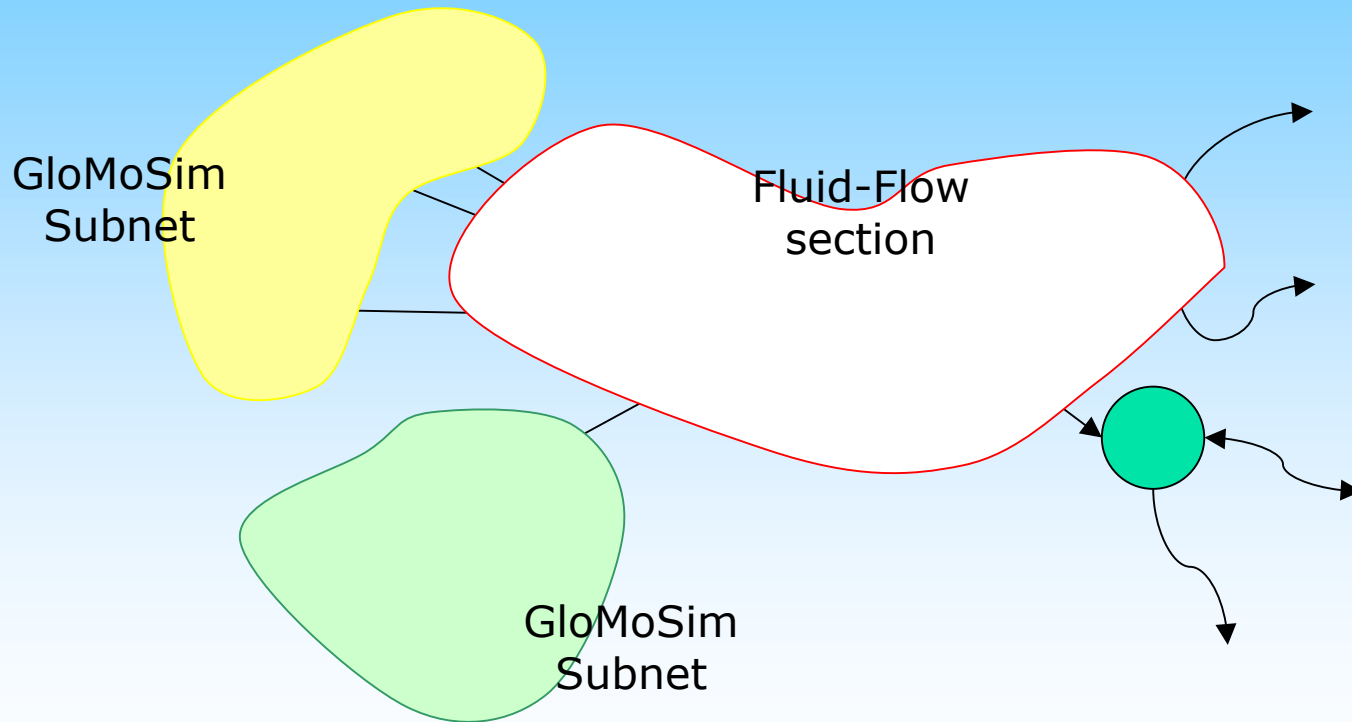
Mixed Mode Simulations (3)

- Ten TCP from Node 0 to 4, One UDP (400kbps) from Node 1 to 5
- Simulation time and accuracy increases as time averaging interval decreases
- Trade-off between simulation accuracy and execution speed



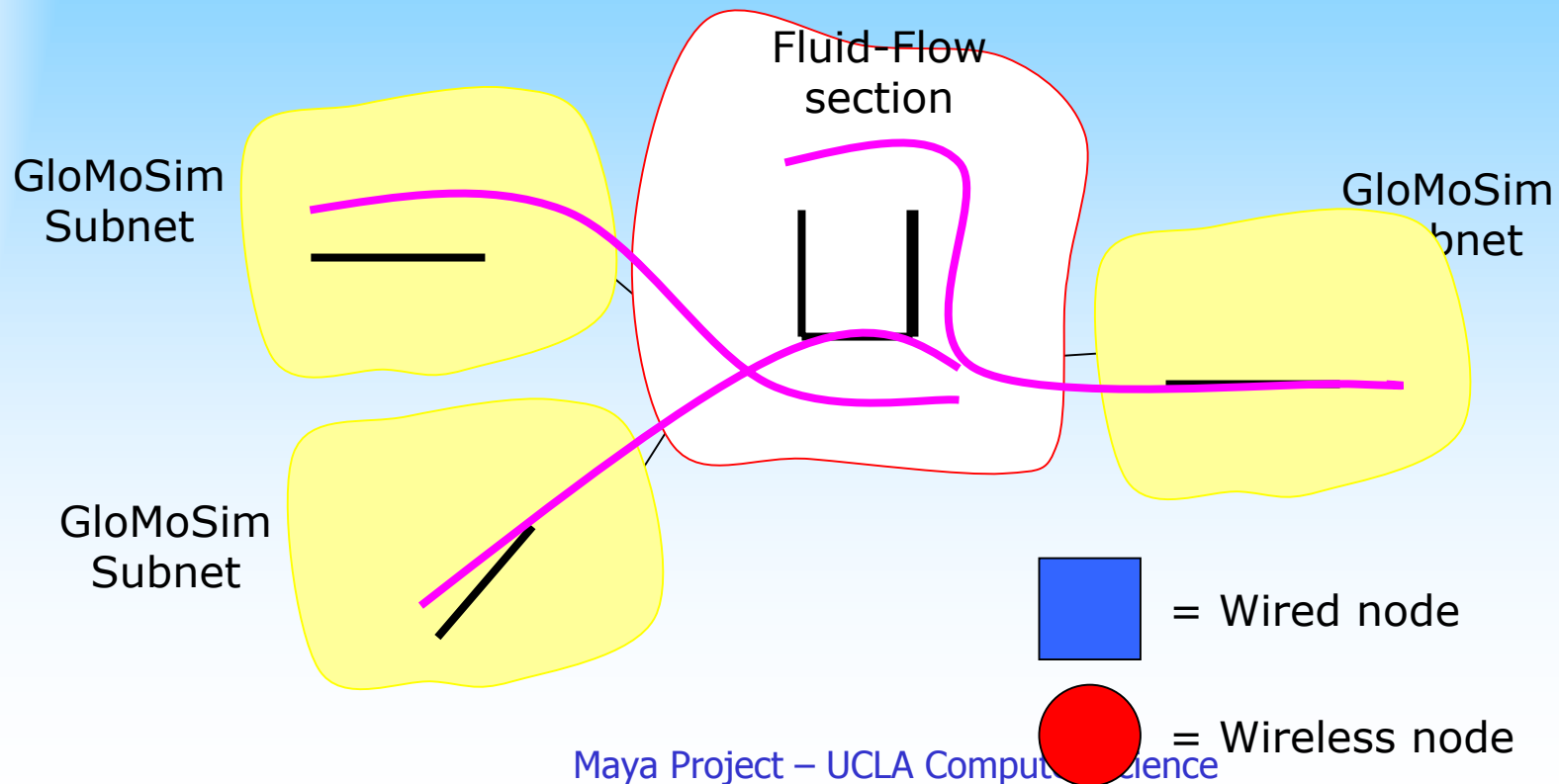
Extension to Subnets

- GloMoSim parts not restricted to be single nodes, can be subnets
- Flexibility in specifying details at each layer



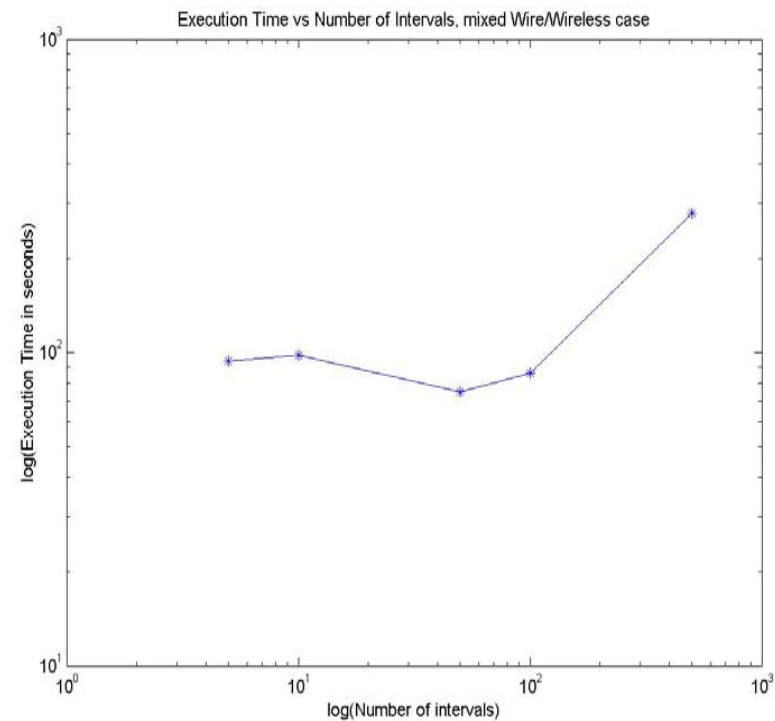
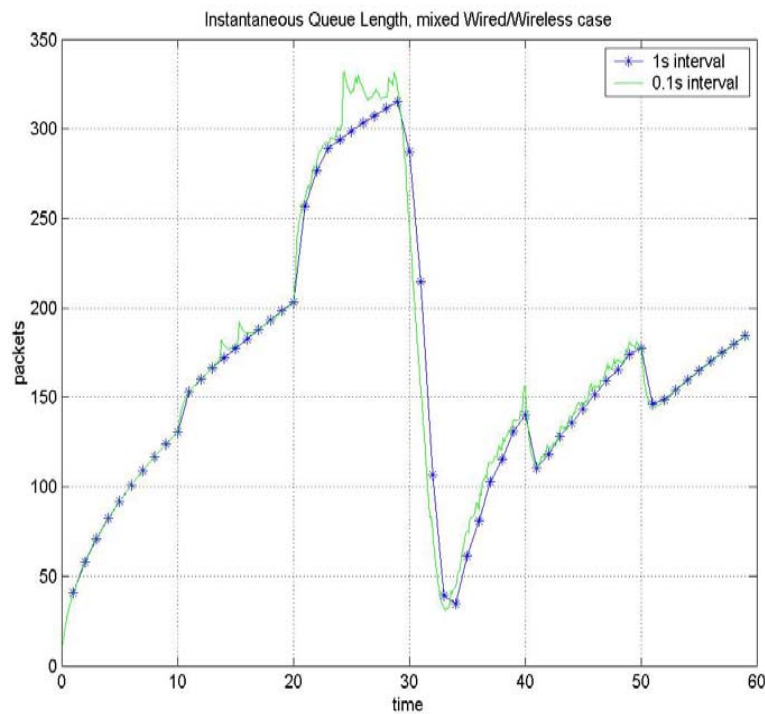
Mixed wired/wireless Simulation (1)

- GloMoSim not restricted to single nodes, can be subnets
- Wired nodes simulated by Fluid-flow model
- Wireless subnet nodes use 802.11 model
- Various TCP and UDP connections through different nodes

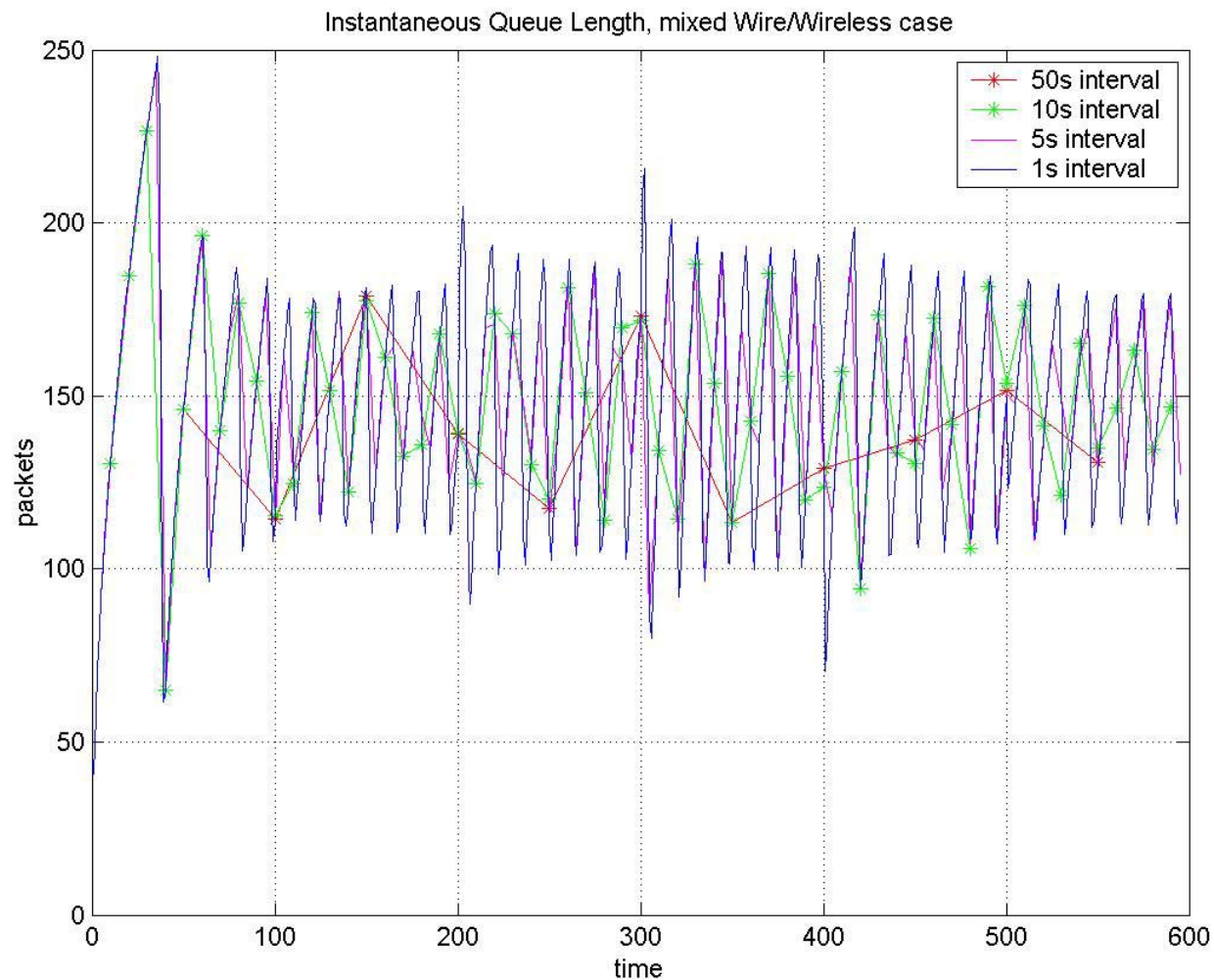


Mixed wired/wireless Simulation (2)

- 1 TCP within Fluid-Flow section
- 1 TCP within each GloMoSim subnet wired/wireless node pair
- 3 UDP (400kbps) across subnets at 10-30s, 20-40s and 30-50s



Mixed wired/wireless



Integration of Operational and Simulated Components



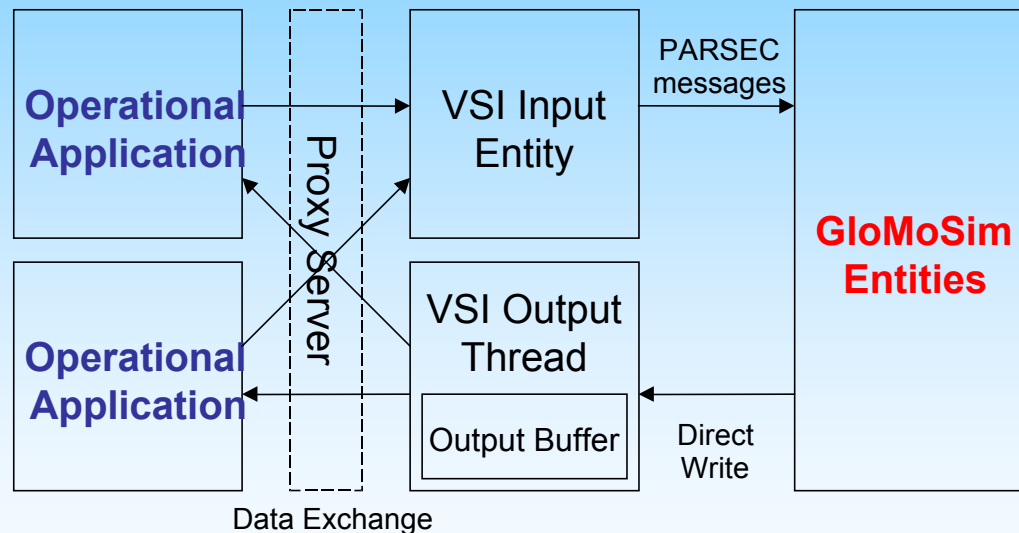
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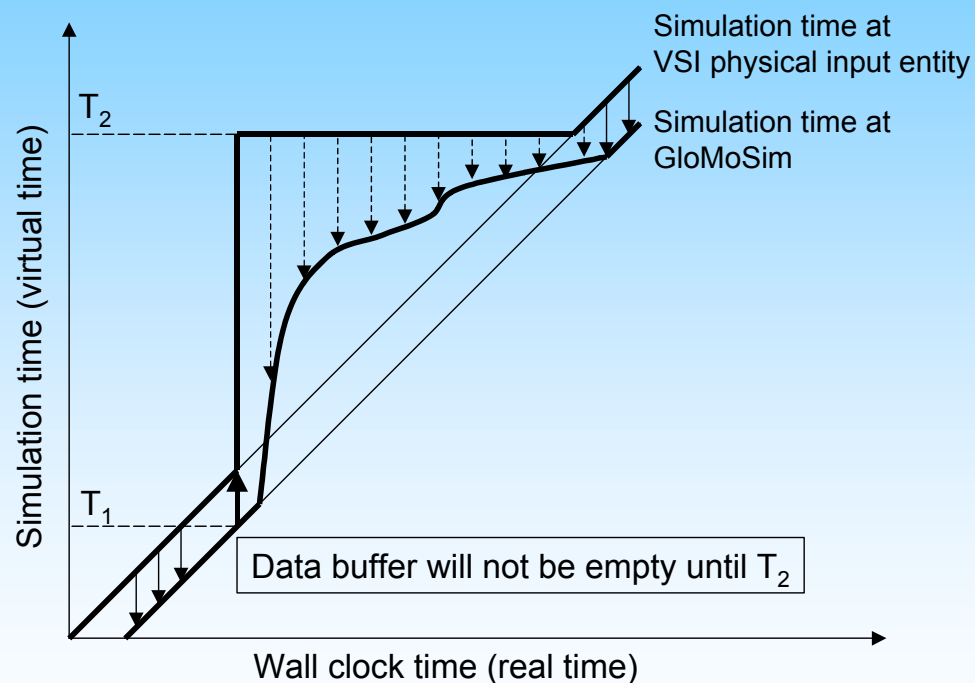
Interfacing to Real Applications (1)

- VSI (Virtual Socket Interface) behaves as if it is a proxy server and communicates with GloMoSim
- Time management (synchronizing real time and simulation time) is done by VSI



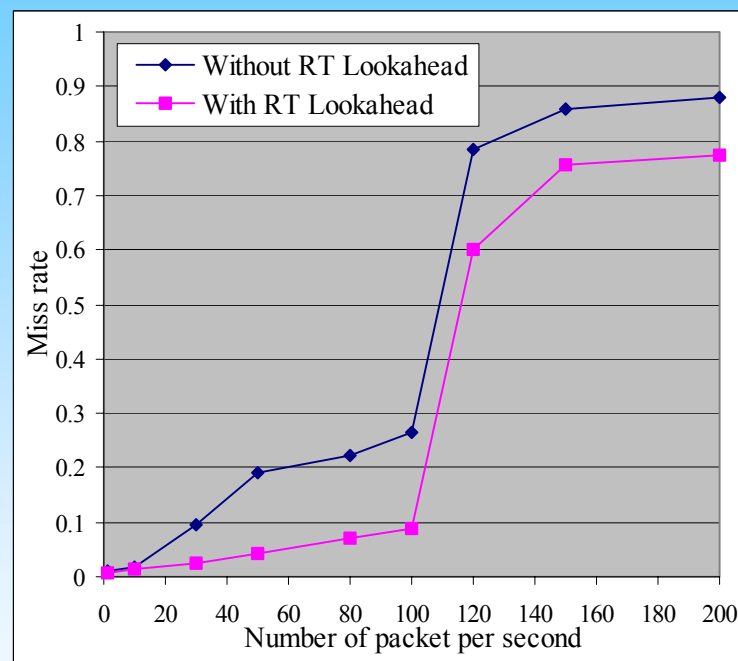
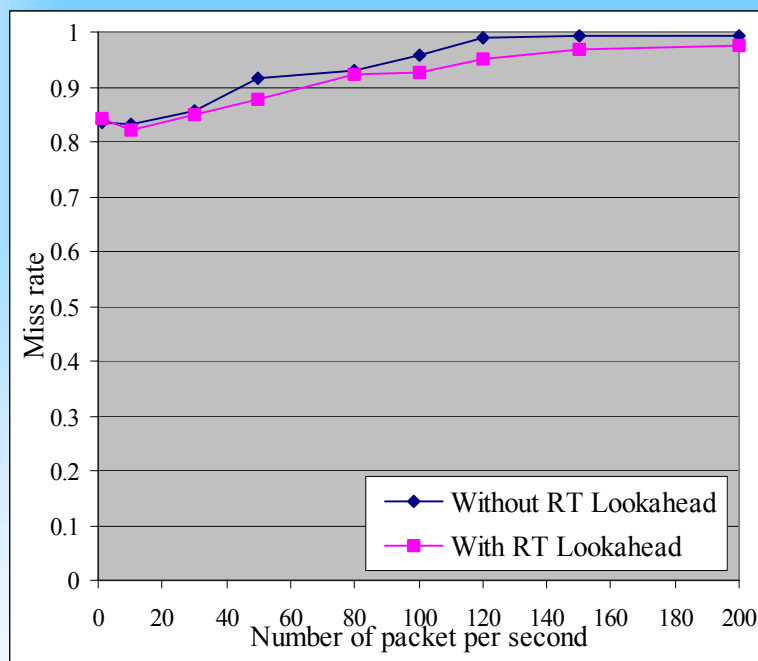
Interfacing to Real Applications (2)

- VSI allows GloMoSim to run ahead of real time by exploiting real-time lookahead (prediction of queue status changes) without compromising emulation results except queue statistics



Impact of Parallel Simulation on Hybrid Scenarios (1)

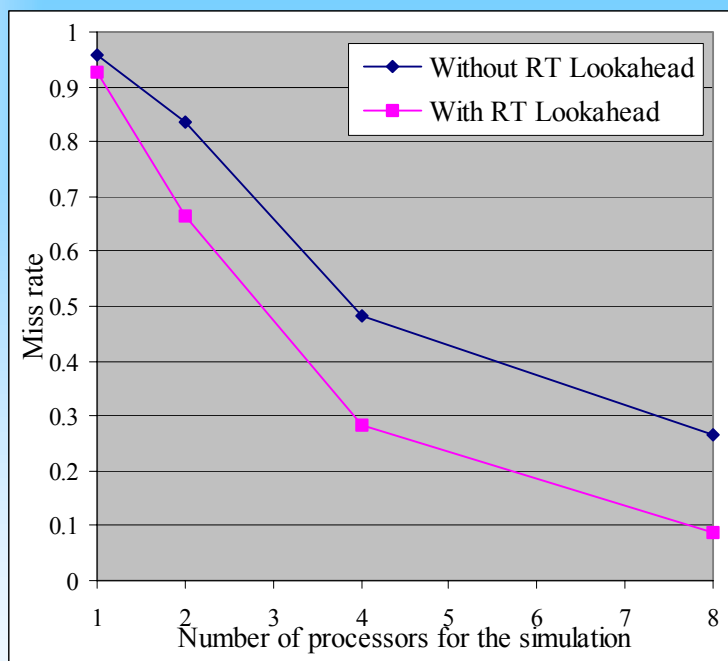
- CBR traffic flows given from non-simulation applications to GloMoSim



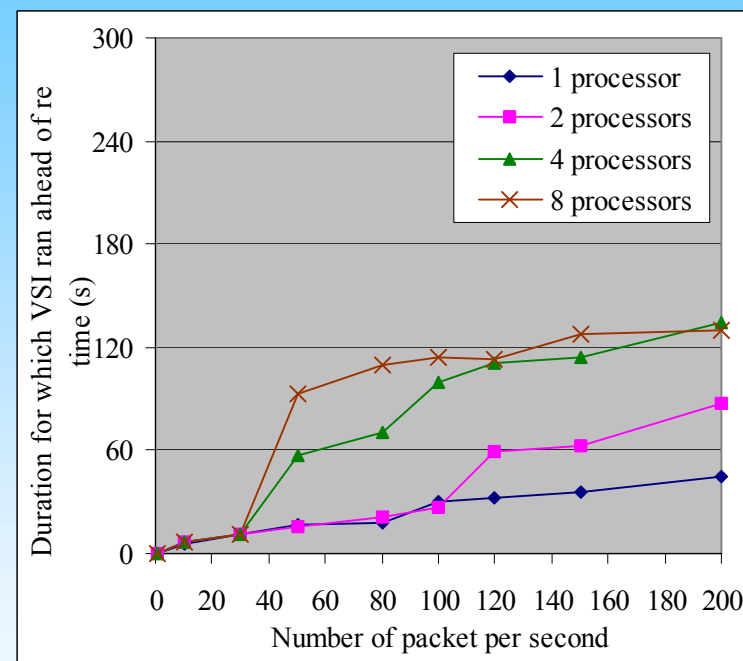
Deadline miss rates in sequential execution Deadline miss rates in parallel execution (8 processors)

Impact of Parallel Simulation on Hybrid Scenarios (2)

- Deadline miss rate goes down as the number of processors used for the simulation increases



Deadline miss rates in parallel execution




Duration for which GloMoSim ran ahead of real time

Technology Transfer/Collaborations

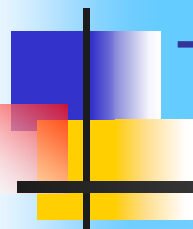


- GloMoSim 2.0 released Jan, 2001
 - <http://pcl.cs.ucla.edu/glomosim>
- Military Tech transfer
 - Use in the Joint Tactical Radio System (JTRS) - 2000
 - **QualNet**: selected by Future Combat System Communications Technology Program (DARPA ATO) - 2001
 - NETWARS interface in development (partial support by CHSSI)
- Collaborations
 - UMASS: integrate fluid flow models into GloMoSim
 - Georgia Tech: integrate GloMoSim into GT backplane
 - SAIC: Integrate QualNet into OSC



Workshop on Parallel & Distributed Simulation (PADS, 2001); May 16-18; Lake Arrowhead, CA

<http://www.eecs.uc.edu/~paw/pads2001/>



TCP Westwood

Mario Gerla